Projection-Based Models for Capturing Human Concepts of Motions

Yohei Kurata and Hui Shi

SFB/TR 8 Spatial Cognition, Universität Bremen
Postfach 330 440, 28334 Bremen, Germany
{ykurata,shi}@informatik.uni-bremen.de

Abstract. Projection-based models, which distinguish spatial relations using a frame of spatial reference, can be used as a foundation for modeling human concepts of motions. In this paper, the existing projection-based models are systematized using short code names that symbolize the models' characteristics. Then, through the observation of these code names, we detect some missing types of models that are applicable to the modeling of motion concepts.

1 Introduction

Projection-based models [1] are spatial models that adopt a frame of spatial reference [2], which partitions the space on/around one object (called *relatum*), and distinguish spatial relations based on the set of partitioned fields over which another object (called *referent*) extends. Two sorts of projection-based models can be used as a foundation for modeling human concepts of motions. One is the models whose relatum is represented by a directed line (*DLine*), called *DLine-relatum models*. They can describe where and how a landmark (referent) extends around/on a path (relatum) and, accordingly, they may capture such path-featured motion concepts as "*go toward*" and "*pass by*". Another useful one is *point-referent models*. They can describe where a destination (referent) is located with respect to a landmark (relatum) and, accordingly, they may capture such goal-oriented motion concepts as "*go to the front of*" and "*go to the north of*". Modeling of such motion concepts is important for the development of systems and machines that work together with ordinary people on spatio-dynamic tasks. In the last two decades, a number of projection-based models have been developed. This paper demonstrates that these models are systematized using short code names that symbolize the models' characteristics (Section 2). Then, making use of these code names, we detect some missing types of models that are applicable to the modeling of human motion concepts (Section 3).

2 Coding Projection-Based Models

The existing projection-based models have adopted a large variety of frames. One distinctive difference of these frames is their shapes: +-, ✳-, and ⊛-shaped frames can be used when the relatum is represented by a point [1, 3, 4]; †- and ‡- shaped frames can be used when the relatum is represented by a straight DLine or a pair of points [5-7]; and ⋕-shaped frames can be used regardless of the relatum's geometric type [8]. In addition, the frames are categorized by their orientation factors [2]:

- *absolute frame*, whose orientation is determined extrinsically by the environment;
- *intrinsic frame*, whose orientation is determined by the relatum's intrinsic orientation (e.g., facing direction, moving direction); and
- *relative frame*, whose orientation is determined by the direction from the third object (*viewer*) to the relatum.

For instance, "*London is to the north of Paris,*" "*Manhattan is on the left-hand side of Statue of Liberty,*" and "S*phinx sits on the left of the pyramid in my view*" refer to the spatial relations defined by the absolute, intrinsic, and relative frames, respectively.

Table 1 summarizes the existing projection-based models and their characteristics. As this table indicates, these models are characterized by a small number of criteria: the frame's shape, its orientation factor, and the geometric type of the referent and the relatum. Meanwhile, the viewer's geometric type seems not important, because the viewer has been always represented by a point because its function is to specify a viewpoint. Based on this observation, we assigned a code name $\mathsf{XyZ}_{m\text{-}n}^{d}$ to each projection-based model in accordance with the following naming rules:

- X: geometric type of the referent—P (point), $\mathsf{P_D}$ (directed point), L (line), $\mathsf{L_D}$ (DLine), $\mathsf{L_{SD}}$ (straight DLine), R (simple region), or A (arbitrary point-set object),
- y: type of frame—a, i, or r (absolute/intrinsic/relative frame),
- Z: geometric type of the relatum—either $\mathsf{P_D}$ or $\mathsf{L_{SD}}$ when an intrinsic frame is adopted (i.e., $\mathsf{y} = \mathsf{i}$), and anything (P, $\mathsf{P_D}$, L, $\mathsf{L_D}$, $\mathsf{L_{SD}}$, R, or A) otherwise,

Table 1. Existing projection-based models, together with their code names (P: point, P_D: directed point, L: line, L_{SD}: straight DLine, R: simple region, A: anonymous point-set object).

Model	Frame		Referent	Relatum	Viewer	Code Name
	Shape	Class				
Single Cross [5]	†	*relative*	P	P	P	$\mathsf{PrP}_{1\text{-}8}$
Double Cross [5]	‡	*relative*	P	$P\times2$		$\mathsf{PrP}_{1\text{-}8}^{2}$
Double Cross [9]		*intrinsic*		L_{SD}	–	$\mathsf{PiL}_{\mathsf{SD}\ 3\text{-}12}$
Models of cardinal directions [1, 8]	⋕	*absolute*	A	A	–	$\mathsf{AaA}_{1\text{-}8}$
Dipole Calculus [10, 11]	|	*intrinsic*	$L_{SD}\times2$		–	$\mathsf{L_{SD}iL}_{\mathsf{SD}\ 0\text{-}2}^{2}$
Ternary Point Configuration Calculus (TPCC) [4]	⊛	*relative*	P	P	P	$\mathsf{PrP}_{1\text{-}24}$
Bipartite Arrangements [6]	‡	*intrinsic*	L_{SD}	L_{SD}	–	$\mathsf{L_{SD}iL}_{\mathsf{SD}\ 3\text{-}12}$
Star Calculus [3]	+, ✳, …	*absolute*	P	P	–	$\mathsf{PaP}_{1\text{-}4n}$
Oriented Point Relation Algebra [12]	+, ✳, …	*intrinsic*	$P_D\times2$		–	$\mathsf{P_DiP}_{\mathsf{D}\ 1\text{-}n}^{2}$
Ego Orientation [7]	+, …	*intrinsic*	P	P_D	–	$\mathsf{PiP}_{\mathsf{D}\ 1\text{-}n}$
Orientation Calculi [7]	‡, …	*intrinsic*	P	L_{SD}	–	$\mathsf{PiL}_{\mathsf{SD}\ m\text{-}n}$

- m/n: number of fields over/around the relatum, respectively, and
- d: number of $\mathrm{XyZ}_{m\text{-}n}$ patterns that composes a single relation (omitted if d =1).

The rightmost column in Table 1 shows the code names assigned to the existing models. For instance, Single Cross [5] is assigned a code name $\mathrm{PrP}_{1\text{-}8}$, which indicates that this model considers a point-like referent placed in a relative frame, which is centered at a point-like relatum and defines one field over the point-like relatum and eight fields around it. Double Cross [5, 9] has two code names: $\mathrm{PrP}_{1\text{-}8}^{2}$ and $\mathrm{PiL}_{\mathrm{SD}\ 3\text{-}12}$. $\mathrm{PrP}_{1\text{-}8}^{2}$ reflects its original definition in [5] where spatial relations are defined as the synthesis of two Single Cross relations ($\mathrm{PrP}_{1\text{-}8}$), whereas $\mathrm{PiL}_{\mathrm{SD}\ 3\text{-}12}$ reflects the reformulated definition in [9] that considers point-DLine relations.

3 Projection-Based Models for Modeling Motion Concepts

As introduced in Section 1, DLine-relatum models and point-referent models are potentially useful for modeling human concepts of motions. Each DLine-relatum model is given a code name like $\mathrm{XiL}_{\mathrm{D}\ m\text{-}n}$ or $\mathrm{XiL}_{\mathrm{SD}\ m\text{-}n}$. The model may be used to capture where and how a landmark X extends around/on a path $\mathrm{L_D}/\mathrm{L_{SD}}$. We currently have $\mathrm{PiL}_{\mathrm{SD}\ m\text{-}n}$ (Double Cross in [9], Orientation Calculi [7]) and $\mathrm{L_{SD}iL}_{\mathrm{SD}\ m\text{-}n}$ (Bipartite Arrangements [6]), while $\mathrm{RiL}_{\mathrm{SD}\ m\text{-}n}$ and $\mathrm{LiL}_{\mathrm{SD}\ m\text{-}n}$ are missing. The models of $\mathrm{RiL}_{\mathrm{SD}\ m\text{-}n}$ and $\mathrm{LiL}_{\mathrm{SD}\ m\text{-}n}$ may capture path-featured motions concepts that presume the landmark's spatial extension, such as "*go into*" and "*go across*." Thus, these models are particularly useful when handling the motions in a small-scale space (e.g., apartments). On the other hand, each point-referent model is given a code name like $\mathrm{PyZ}_{m\text{-}n}$. The model may be used to capture the relative location of the destination P with respect to a landmark Z. We currently have $\mathrm{PaA}_{m\text{-}n}$ (Cardinal Direction [1, 8]), $\mathrm{PiP}_{\mathrm{D}\ m\text{-}n}$ (Ego Orientation [7]), $\mathrm{PiL}_{\mathrm{SD}\ m\text{-}n}$ (Double Cross in [9], Orientation Calculi [7]), and $\mathrm{PrP}_{m\text{-}n}$ (Single Cross [5] and TPCC [4]). Thus, for every geometric type of landmarks, we can consider a point-referent model that adopts an absolute or intrinsic frame (recall that the relatum is limited to $\mathrm{P_D}$ or $\mathrm{L_{SD}}$ when the intrinsic frame is adopted). On the other hand, as for the point-referent models with a relative frame, $\mathrm{PrL}_{m\text{-}n}$ (and its variants $\mathrm{PrL}_{\mathrm{D}\ m\text{-}n}$ and $\mathrm{PrL}_{\mathrm{SD}\ m\text{-}n}$) and $\mathrm{PrR}_{m\text{-}n}$ are missing. The models of these categories can be used for modeling motion concepts in which the goal is associated with linear or region-like landmarks. For instance, two point-referent models, categorized into $\mathrm{PrL}_{1\text{-}4}$ and $\mathrm{PrR}_{1\text{-}4}$, may illustrate whether the goal is located on the left, right, front, or back of a linear landmark (e.g., a station platform) and a region-like landmark (e.g., a park) as seen from the mover's start point, respectively.

4 Conclusions

DLine-relatum models and point-referent models, both subsets of projection-based models, are useful for qualitative characterizations of spatial movements using landmarks. This paper demonstrated that these models are systematized by short code names that reflect the models' prominent characteristics. The comparison of the code names leaded to the identification of four missing types of models—$\mathrm{RiL}_{\mathrm{SD}\ m\text{-}n}$,

$\mathrm{LiL}_{\mathrm{SD}\,m\text{-}n}$, $\mathrm{PrL}_{m\text{-}n}$, and $\mathrm{PrR}_{m\text{-}n}$—that are potentially useful for modeling motion concepts. Currently we are developing a series of models that belong to $\mathrm{RiL}_{\mathrm{SD}\,m\text{-}n}$ and applying these models to the modeling of a number of motion concepts that concern region-like landmarks in an effective way [13]. The exploration of the other potential models that belong to $\mathrm{LiL}_{\mathrm{SD}\,m\text{-}n}$, $\mathrm{PrL}_{m\text{-}n}$ or $\mathrm{PrR}_{m\text{-}n}$ are also desirable for enriching the foundation for handling human concepts of motions computationally.

Among the models reviewed in this paper, TPCC [4] introduces a new concept of projection-based modeling—*near-far* distinction. Although nearness is a subjective concept, TPCC expediently defines *near* and *far* fields based on the viewer-relatum distance, as this yields some nice properties in its calculus [4]. It is an interesting topic to apply such a *near-far* distinction to other projection-based models and analyze how it improves the calculus, as well as the modeling capability of spatial concepts.

References

1. Frank, A.: Qualitative Spatial Reasoning: Cardinal Directions as an Example. International Journal of Geographical Information Science 10, 262-290 (1996)
2. Levinson, S.: Language and Space. Annual Review of Anthropology 25, 353-382 (1996)
3. Renz, J., Mitra, D.: Qualitative Direction Calculi with Arbitrary Granularity. In: Zhang, C., Guesgen, H., Yeap, W.-K. (eds.): 8th Pacific Rim International Conference on Artificial Intelligence, pp. 65-74 (2004)
4. Moratz, R., Nebel, B., Freksa, C.: Qualitative Spatial Reasoning about Relative Position: The Tradeoff between Strong Formal Properties and Successful Reasoning about Route Graphs In: Freksa, C., Brauer, W., Habel, C., Wender, K. (eds.): Spatial Cognition III, LNAI, vol. 2685, pp. 385-400. Springer (2003)
5. Freksa, C.: Using Orientation Information for Qualitative Spatial Reasoning. In: Frank, A., Campari, I., Formentini, U. (eds.): International Conference GIS - From Space to Territory: Theories and Methods of Spatio-Temporal Reasoning in Geographic Space, LNCS, vol. 639, pp. 162-178. Springer (1992)
6. Gottfried, B.: Reasoning about Intervals in Two Dimensions. In: Thissenm, W., Pantic, M., Ludema, M. (eds.): IEEE International Conference on Systems, Man and Cybernetics, pp. 5324-5332 (2004)
7. Krieg-Brückner, B., Shi, H.: Orientation Calculi and Route Graphs: Towards Semantic Representations for Route Descriptions. In: Raubal, M. (ed.): GIScience 2006, LNCS, vol. 4197, pp. 234-250. Springer (2006)
8. Goyal, R., Egenhofer, M.: Consistent Queries over Cardinal Directions across Different Levels of Detail. In: Tjoa, A.M., Wagner, R., Al-Zobaidie, A. (eds.): 11th International Workshop on Database and Expert Systems Applications, pp. 876-880 (2000)
9. Zimmermann, K., Freksa, C.: Qualitative Spatial Reasoning Using Orientation, Distance, and Path Knowledge. Applied Intelligence 6, 49-58 (1996)
10. Schlieder, C.: Reasoning about Ordering. In: Frank, A., Kuhn, W. (eds.): COSIT '95, LNCS, vol. 988, pp. 341-349. Springer (1995)
11. Moratz, R., Renz, J., Wolter, D.: Qualitative Spatial Reasoning about Line Segments. In: Horn, W. (ed.): 14th European Conference on Artificial Intelligence, pp. 234-238. IOS Press (2000)
12. Moratz, R., Dylla, F., Frommberger, L.: A Relative Orientation Algebra with Adjustable Granularity. In: Workshop on Agents in Real-Time and Dynamic Environments (2005)
13. Kurata, Y., Shi, H.: Interpreting Motion Expressions in Route Instructions Using Two Projection-Based Spatial Models. To appear in: 31st Annual German Conference on Artificial Intelligence (KI 2008), LNAI. Springer (2008)